WOW

Engineering and Economics Group

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Outline

a) Turbines – On-shore v Off-shore
b) Foundation Options and Installations
c) Meteorological Considerations
d) Transmission/Interconnection
e) Economics, Finance and Risk – N/A
f) Appendix

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Off-shore Turbines

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Differences between on-shore and off-shore turbines

- Turbines are generally a larger version of on-shore turbines. Currently Developing of a 7.5MW turbine.
- Humidity and corrosion protection
- Boat or helicopter access platforms
- Redundant subsystems and sensors
- Transformer in tower

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Existing Off-shore turbine Suppliers

Manufacturer	Turbine	Capacity (MW)	Rotor Diam(M)
General Electric	3.6s	3.6	111
Siemens	SWT-3.6-107	3.6	107
Dewind	D8.2	2	80
Vestas	V90-3.0	3	90
Nordex	N90	2.5	90
REPower	5M	5	126
ScanWind	SW-110-3500 DL	3.5	110
Bard		5	122
WinWind	WWD-3	3	100
Multibrid	M5000	5	116
Enercon	Development	4.5	112

Great Lakes Wind Turbine Adaptations

- Coatings to prevent ice accumulation
- No need for salt water protection such as coatings and humidity protection
- No need for Helicopter access platforms
- No need for tall transition sections for high wave and tide action.
- Submarine cables require less corrosion protection.

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Future Developments in Off-shore Technology

- Higher tip speed rotors (weight reduction)
- Two blade rotors (weight reduction)
- Improved diagnostics and sensors to reduce access intervals.
- Direct drive generators (Reliability)

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Off-shore Capital Costs

- No American experience
- No Great Lakes Experience
- Estimate costs relative to on-shore costs
- European experience shows capital costs are 50%-100% higher than on-shore

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Wind Turbine Cost Drivers

- On-shore and off-shore
  - Wind Turbine Prices are increasing
  - Commodity prices
  - Monetary Exchange Rates
  - Wind Turbine Demand
- Off-shore
  - Increased commercialization of some technologies decreasing cost differential between on-shore and off-shore
  - Some newer technologies' costs are unknown

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Off-shore Wind O&M Methods & Costs

- Methods
  - Specialized boat access
  - Ampelmann platform
  - Access in ice conditions
- Costs
  - No American Experience
  - No Great Lakes Experience
  - O&M costs are higher on a $/kW or per turbine basis compared to on-shore turbines
  - Studies show O&M Costs to be similar to On-shore on $/kwh basis due to higher capacity factors.
  - Estimating O&M costs relative to on-shore turbines with range of costs.

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Turbine Technology Information Gaps

- O&M Costs
- Capital Costs
- Information from other states or Canadian Great Lakes projects

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Foundation Options and Installation

Meteorological and Wind turbine Construction Sub Group

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Foundation Design Criteria

- Criteria required for design (design drivers in bold)
  - Geotechnical
  - Underwater currents
  - Water levels
  - Lake bathymetry
  - **Wave characteristics**
  - **Icing climate**
  - **Wind loading**

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Information required - if available

- 50-year return wave (used in EU off-shore designs)
  - 100-year return wave estimated at 27'-30' for Wisconsin Great Lakes sites
- Design wind speed
- Design ice criteria
  - Army Corps of Engineers – 5,000 lb/ft2 static ice load and 300 lb/ft2 max design ice load
- Underwater current design criteria
  - Not a design driver

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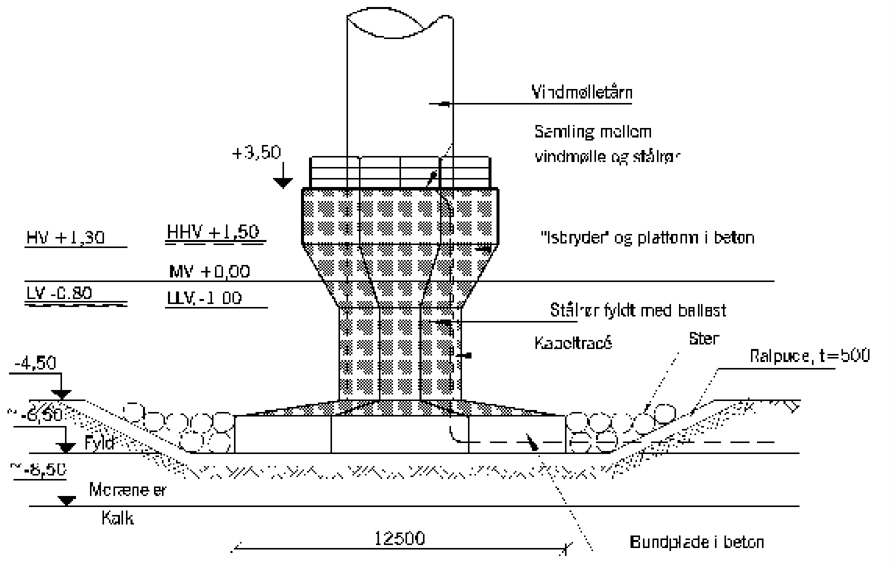
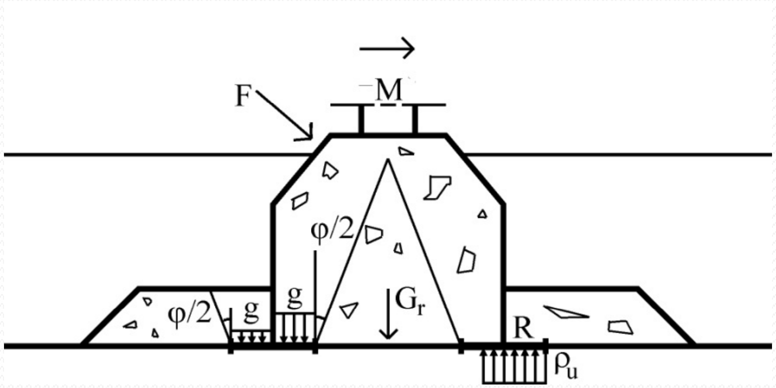
Ice cones – conically shaped





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Foundation Information Shallow Water

- Concrete gravity base foundation (0-10 m depth)
  - Well-known
  - Very little opportunity to use in WI due to water depths
- Steel gravity foundation (0-10 m depth)
  - Not as commonly used in Europe
- Conical cylindrical shell with ring footing (5-15 m depth)
  - Little less costly due to use of aggregate and gravel
  - Developed by Finns for use in high ice areas
  - No significant use yet
- Monopile foundation (3-25 m depth)
  - Most commonly used in Europe
  - Requires jack-up barge to install

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Foundation Information Transitional and Deep Water

- Suction caisson (bucket) (3-20 m depth?)
  - Suction the tube to the bottom rather than drilling
  - Many benefits and might work to lower depths but is new technology
- Tripod/tetrapod technology (20-80 m depth)
  - Applicable to deeper water, e.g. Beatrice site
  - May require heavy lift barge; existing barges may not be able to get into Great Lakes
- Floating foundations (>25 m depth)
  - Allows installations in deep water
  - Has not been demonstrated on a commercial scale

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Foundation Information
Transitional and Deep Water

- Floating to Fixed Concept
  - Tug deployable
  - Not been demonstrated on a large-scale commercial wind project
- Dutch tri-floater
  - Tug deployable
  - Not been demonstrated on a large-scale commercial wind project
- Deep water concepts requiring further demonstration
  - WindSea (35-200 meters)
  - Blue H Prototype (tested 108 meters)
  - SWAY concept (>150 meters)

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Foundation installation process

- Gravity foundation
  - Ideally build form/shell on land and tow/float to sea
  - Prepare lake bed to accept foundation
  - Can build at sea using coffer dams, but an expensive option
  - Place foundation and fill if required
  - Install transition piece
- Monopile
  - Drive with pile driving equipment at sea
  - Install transition piece

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Installation equipment options

- Shallow water installations
  - Converted turbine installation vessel (TIV) – Jack up barge
  - Purpose built TIV
  - Merlin Off-shore Wind Turbine Installation System
  - Heavy lift crane barge (Beatrice)
- Deep water installations
  - Standard options
    - Jack up barge, purpose built TIV, Merlin System, heavy lift barge
  - Options being evaluated (tug deployable)
    - Floating to Fixed Wind Energy Concept, Tri-floater, WindSea, Blue H Technology

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off-shore Vessel Availability

- Jack up barges
  - Most commonly used, but in high demand
  - Wind industry competing w/ oil industry for these vessels
  - Trillium Power Energy plans to build TIV for installing 5 MW units on Lake Ontario
- TIV's, Merlin System, additional options
  - Being evaluated as options to jack up technology
  - Can be more costly – preliminary
- Heavy lift crane barge
  - Has been used at Beatrice site

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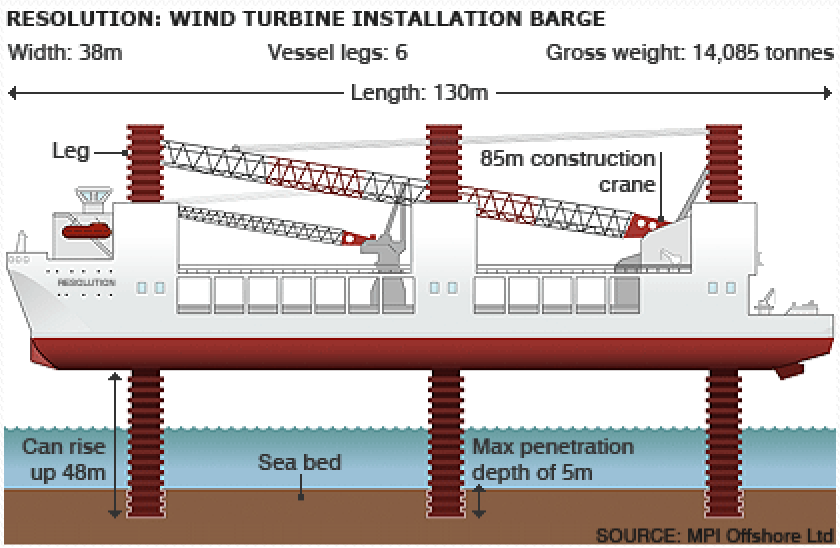
Jack Up Barge



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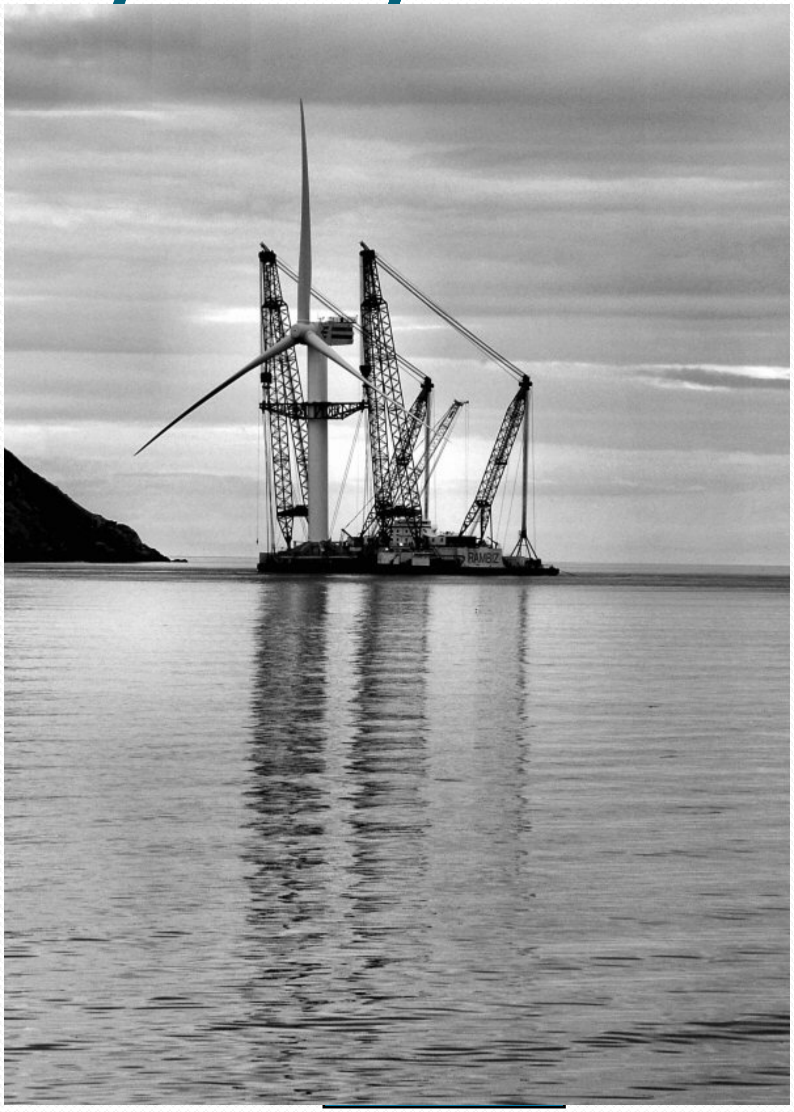
Heavy duty crane barge



Wind Turbine Decommissioning Process and Cost

- Would involve similar equipment used for installation
- Process would be:
  - Remove rotor w/ blades
  - Transport rotors to port for dismantling, recycling, reuse, or to landfill
  - Remove and transport tower sections and transition pieces to port
  - Remove and recycle transmission system and foundation materials
  - Restore lake bed

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Decommissioning Process Cont.

- Key issue w/ decommissioning is finding a recycling stream for fiberglass blades.
- NREL estimated decommissioning costs at 3% of total project cost.

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Meteorological Conditions

Meteorological and Wind turbine Construction Sub Group

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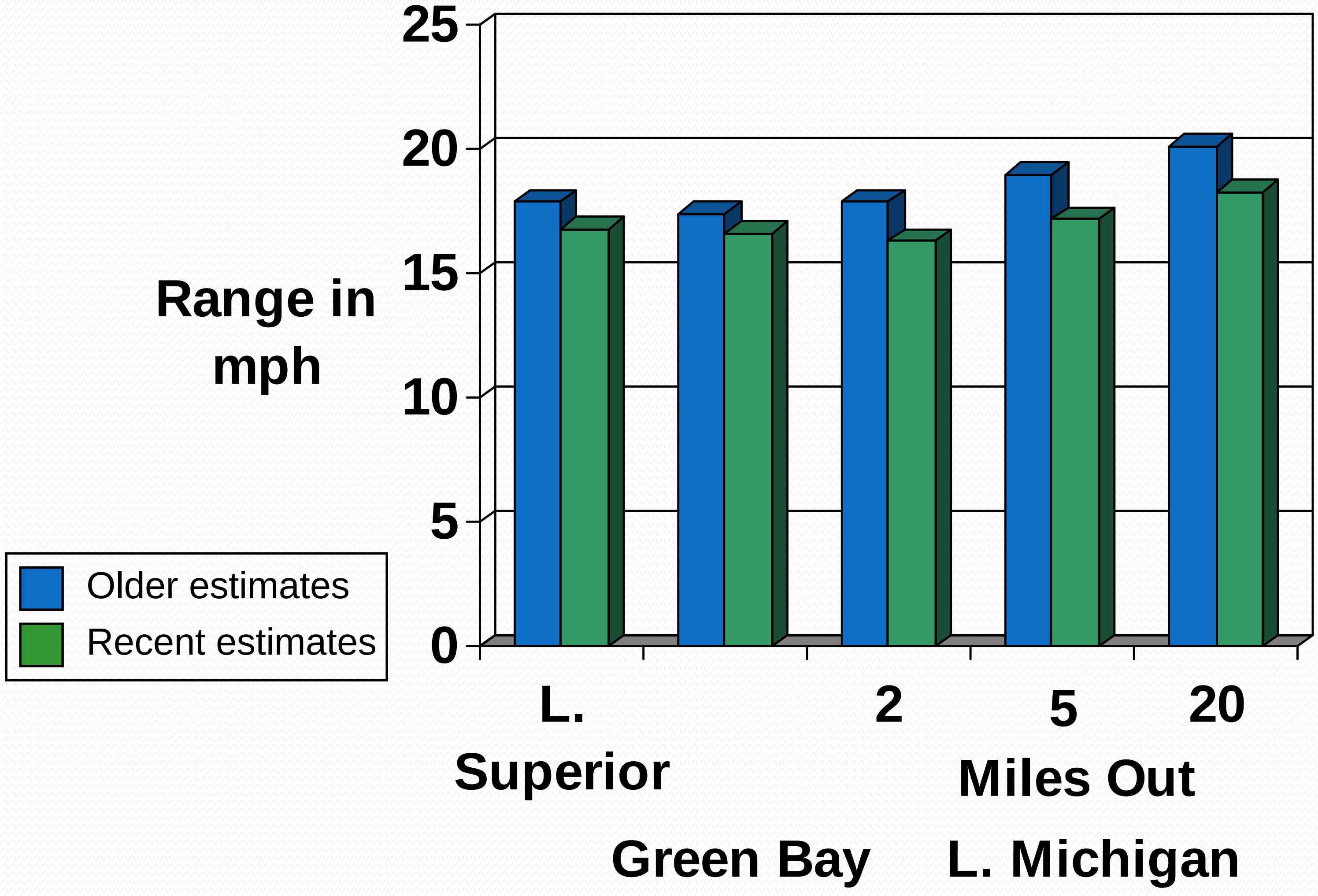
WI Offshore Wind Resources



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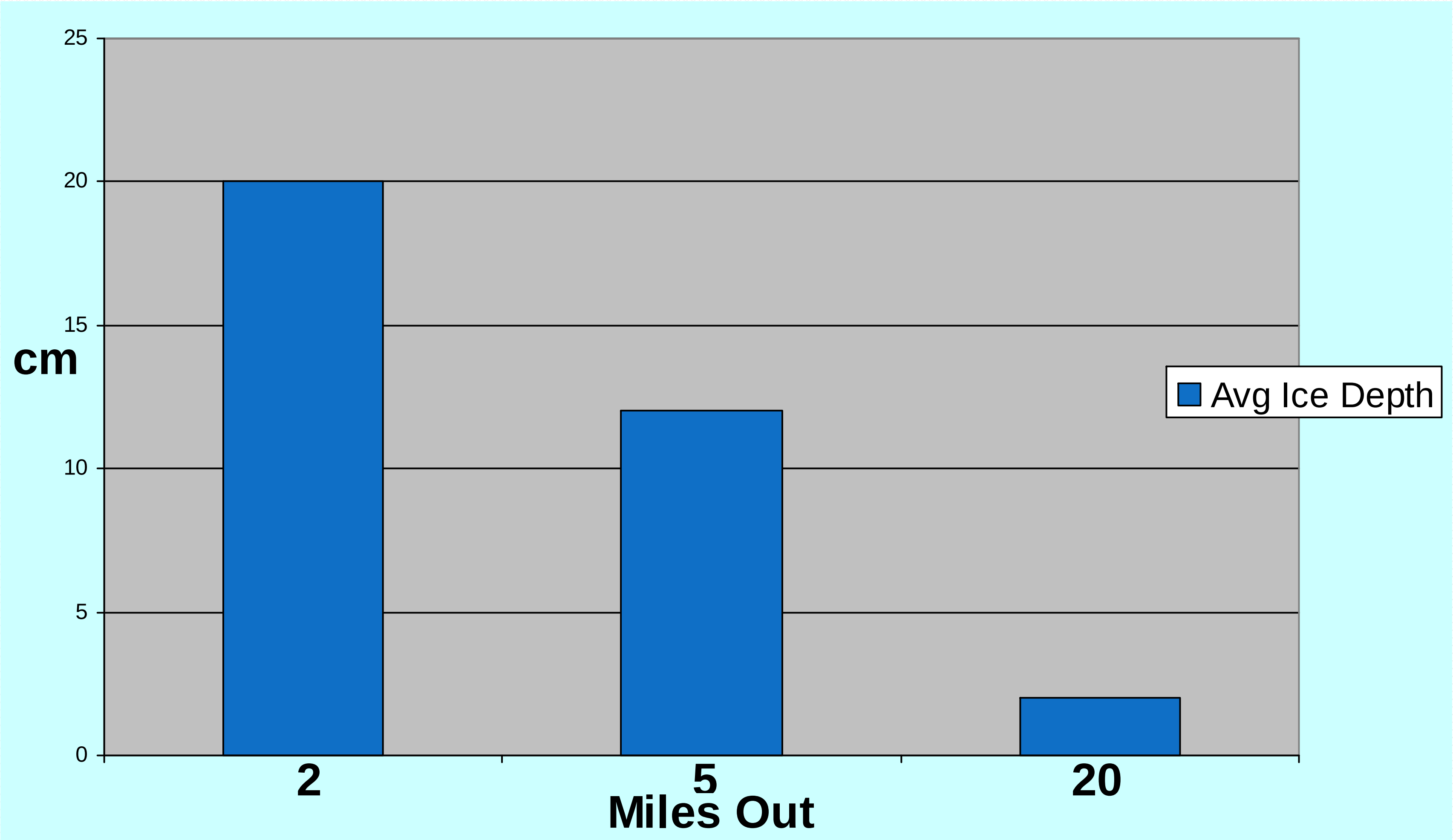
Lake Michigan Ice Production in Typical S.E. WI Winter



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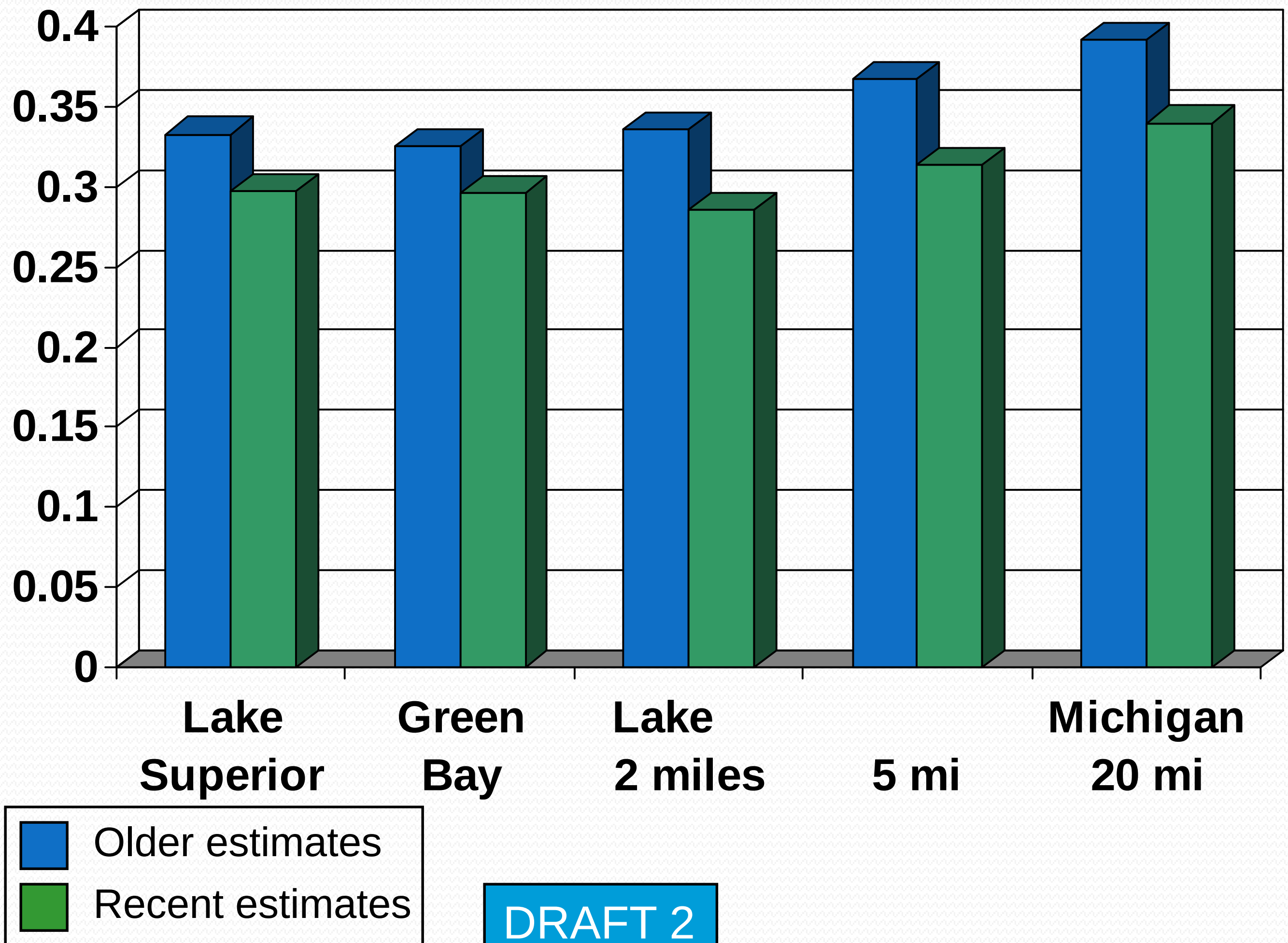
WI off-shore Net Capacity Factors After Wind Farm Losses (>100-MW Projects)



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Transmission/ Interconnections

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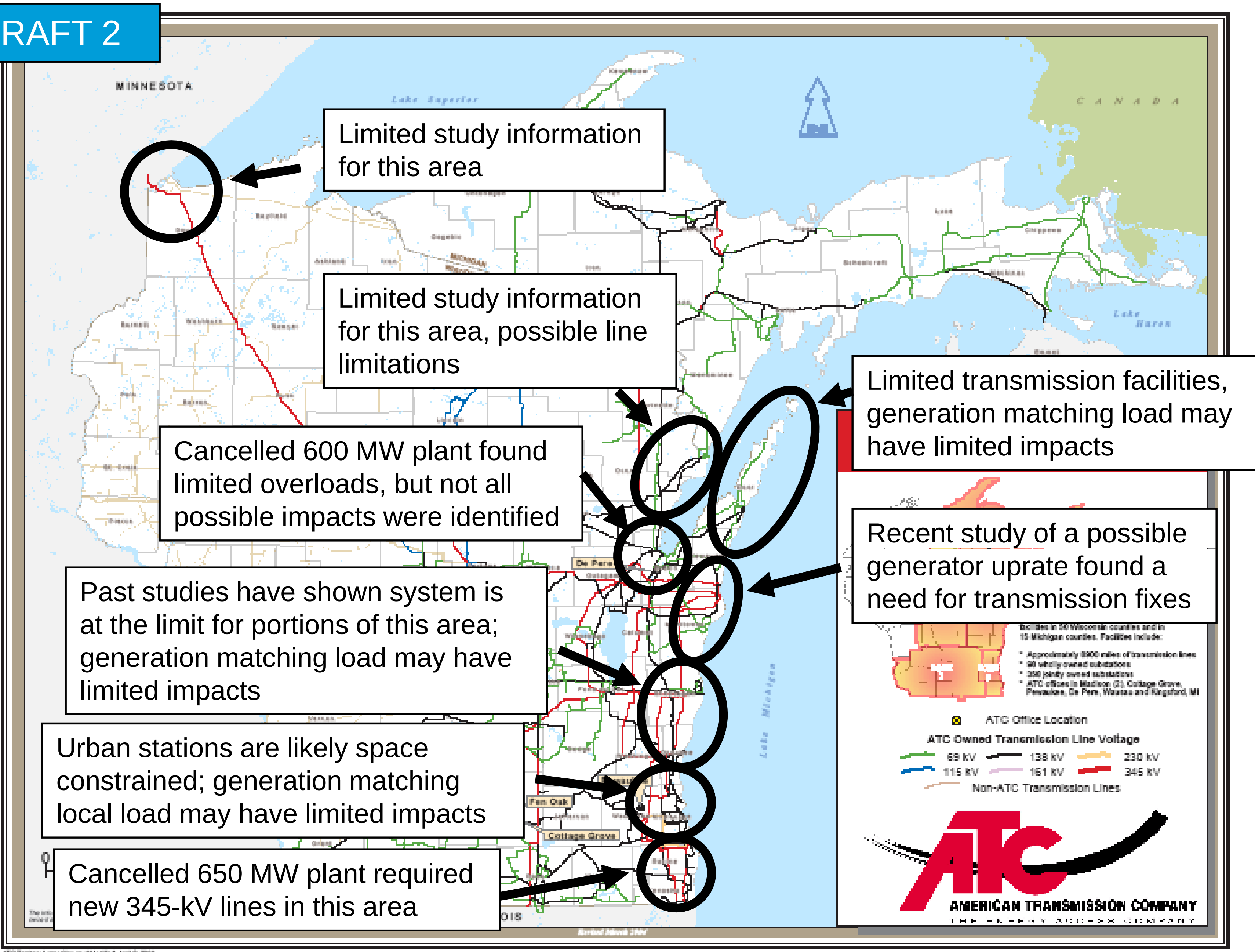
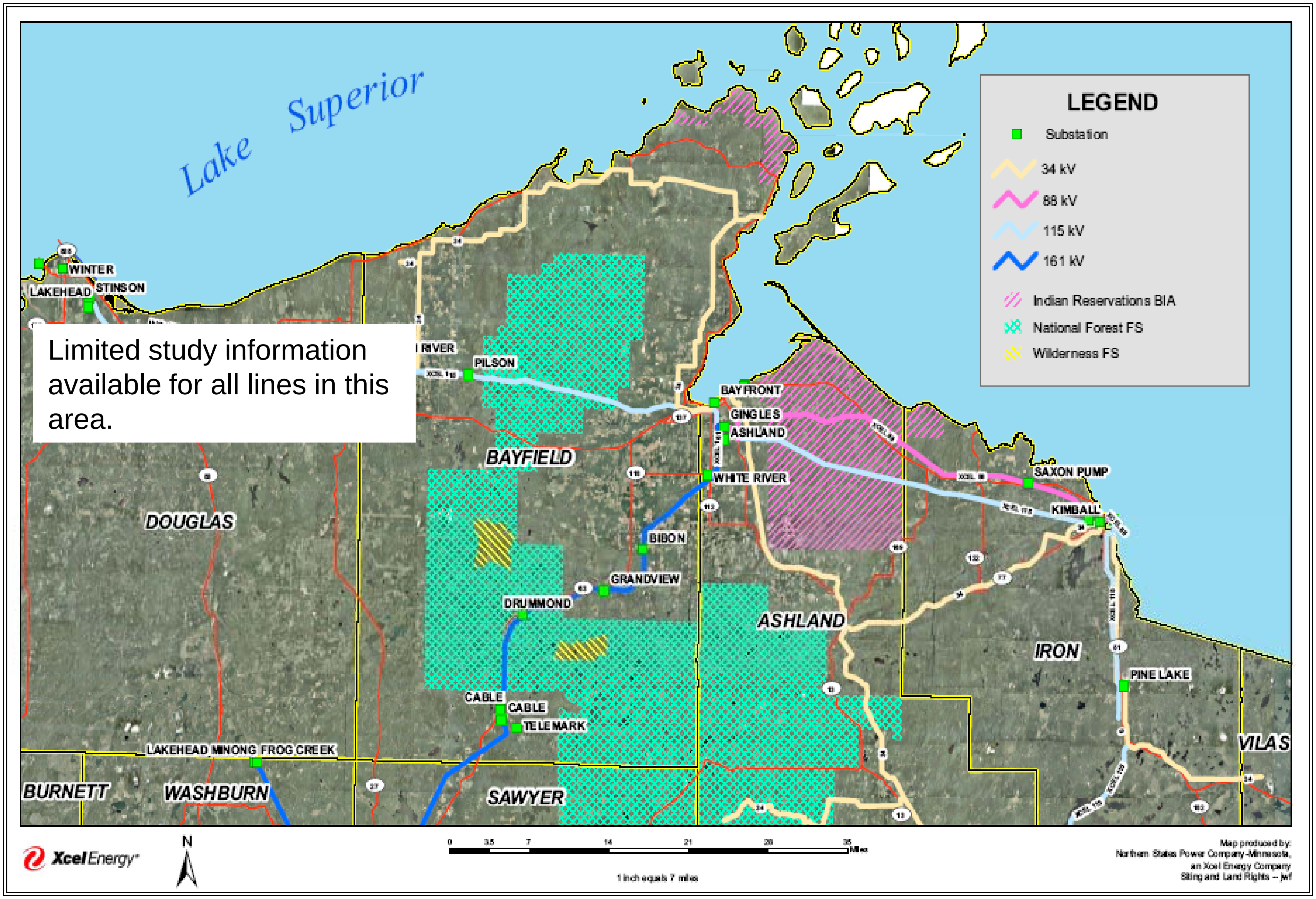


MINNESOTA
Lake Superior
CANADA
Lake Huron
Lake Michigan
De Pere
Fon Oak
Cottage Grove
Limited study information for this area
Limited study information for this area, possible line limitations
Limited transmission facilities, generation matching load may have limited impacts
Cancelled 600 MW plant found limited overloads, but not all possible impacts were identified
Recent study of a possible generator uprate found a need for transmission fixes
Past studies have shown system is at the limit for portions of this area; generation matching load may have limited impacts
Urban stations are likely space constrained; generation matching local load may have limited impacts
Cancelled 650 MW plant required new 345-kV lines in this area
ATC Office Location
ATC Owned Transmission Line Voltage
69 kV
115 kV
138 kV
161 kV
230 kV
345 kV
Non-ATC Transmission Lines
ATC
AMERICAN TRANSMISSION COMPANY



Lake Superior
LEGEND
Substation
34 kV
69 kV
115 kV
161 kV
Indian Reservations BIA
National Forest FS
Wilderness FS
Limited study information available for all lines in this area.
WINTER
LAKEHEAD
STINSON
PILSON
BAYFRONT
GINGLES
ASHLAND
WHITE RIVER
SAXON PUMP
KIMBALL
BIBON
GRANDVIEW
DRUMMOND
CABLE
CABLE
TELEMARK
LAKEHEAD MINONG FROG CREEK
PINE LAKE
BAYFIELD
DOUGLAS
ASHLAND
IRON
VILAS
BURNETT
WASHBURN
SAWYER
Xcel Energy
N
1 inch equals 7 miles
Map produced by:
Northern States Power Company-Minnesota,
an Xcel Energy Company
Siting and Land Rights – jwf

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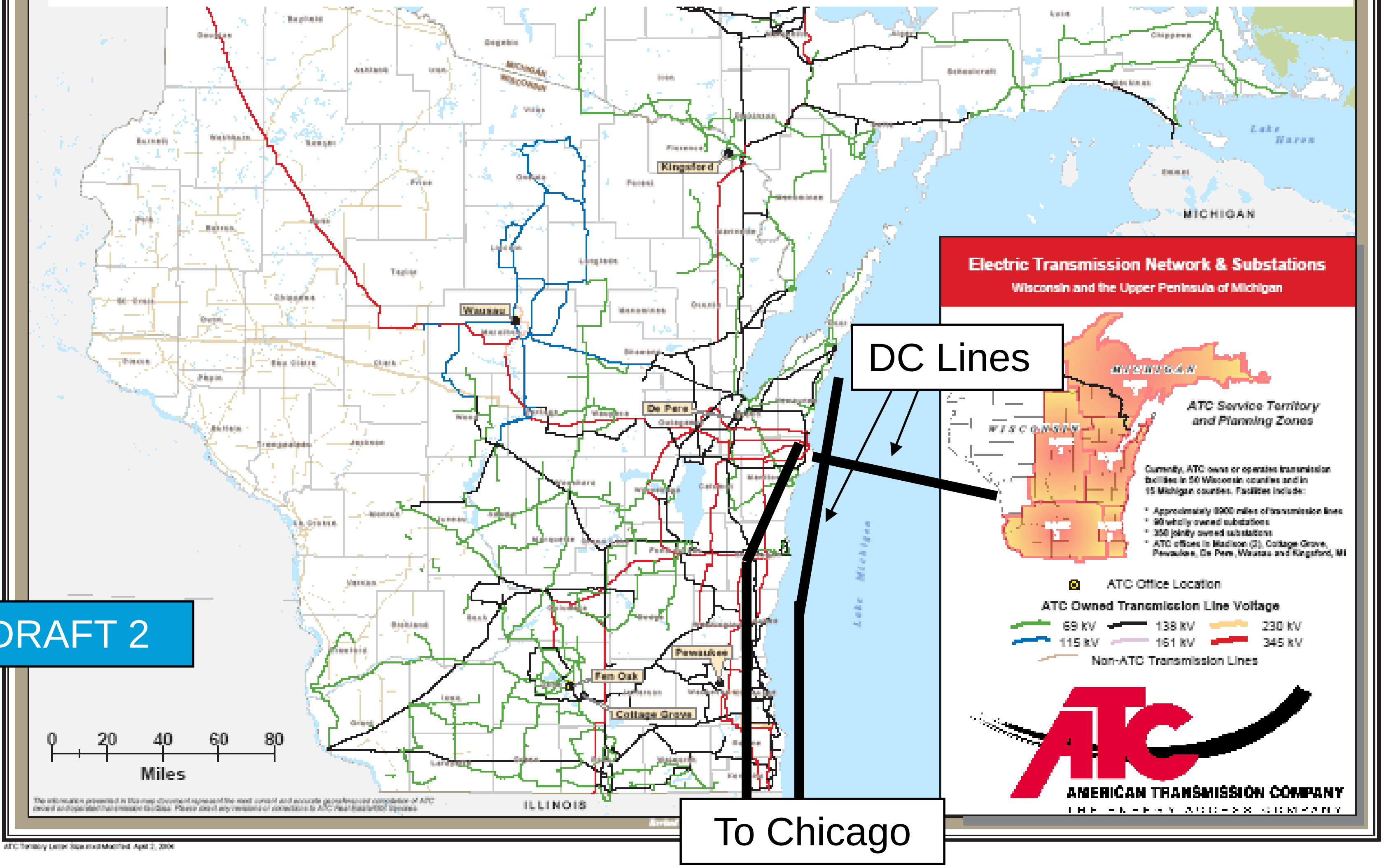
Team members' suggestions for possible "backbone" transmission additions to move wind power.



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APPENDIX

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off-shore Wind Turbine Foundation Information – Shallow Water			
Foundation Type	Pros	Cons	Water Depth
Concrete gravity base foundation	• Well-known technology. • Can construct on-shore and float to site. • Rigid tower base. • Can add conical section at top to act as ice breaker.	• Size/weight. • Decommissioning/removal. • Special foundation preparation may be required – depending on soil type. • Foundation toe needs scour protection.	0m to 10m – cost prohibitive at depths > 10m
Steel gravity foundation	• Considerably lighter than concrete foundations. • Low weight of steel cylinders allows more rapid foundation installation. • Foundation can be made on-shore. • No piling. • Can remove completely and repositioned. • Can be easily inspected.	• Cylinder needs to be filled w/ granular material to withstand waves and ice. • Need to install erosion protection around foundation base. • Time consuming weld details. • Need large area at laydown area to construct.	0m to 10m
Thin-walled cylindrical shell w/ ring footing – conical shape and filled w/ granular material (steel gravity foundation designed to withstand ice flows)	• More rigid than a pile structure. • Designed for areas w/ waves and ice ridge action (e.g. Baltic Sea and Great Lakes) • Steel shells can be transported by barge. • 50-year design life.	• Needs firm/hard bed conditions. • Erosion protection required. • Cylinder needs to be filled w/ granular material to withstand waves and ice.	5m to 15m
Monopile foundation	• Relatively simple to manufacture and construct. • No bed preparation required. • Foundation flexibility enables tuning of structure dynamic characteristics. • Quick installation. • Low sensitivity to underwater erosion.	• Requires specialized installation equipment. • Sensitive to solids (rocks) when driven. • Flexible at greater water depths. • Not suited for weak soils. • Difficult to modify for ice protection. • Price increases with respect to depth more rapidly in area with ice pressure concerns.	3m to 25m (some sources up to 30m)

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off-shore Wind Turbine Foundation Information – Transitional and Deep Water			
Foundation Type	Pros	Cons	Water Depth
Suction caisson (bucket)	• Simpler/quicker construction procedure. • Less/smaller installation equipment required. • Easy to remove. • Can be used in concert with deeper water options.	• New technology. • Inexpensive installation. • Installation proven in limited range of materials.	3m to 20m
Tripod/tetrapod foundation Submerged tubular steel/concrete w/ guy wire attachments to lake bed	• Applicable to deeper water. • No or limited seabed preparations. • Can be made on-shore. • Easy to remove. • Suction bucket attachment could minimize lake bed disturbances. • Guyed system cheaper if deeper.	• Increases ice load unless modified w/ transition piece. • Boat access difficult unless modified. • Sensitive to solids (rocks) when driven piles used for attachment. • May require heavy lift barge. • Guy wires could restrict fishing/anchoring	20m to 80m
Floating foundations	• Allows installations in deep water. • Can use conventional installation equipment (i.e tugboats) versus barges • Turbine sighting and interconnection flexibility	• Methods primarily in conceptual phase. • Stability, access and structural fatigue issues need to be analyzed. • Uncertain cost. • Expensive anchors (when applicable).	> 25m

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off-shore Wind Turbine Foundation Information – Transitional and Deep Water			
Foundation Type	Pros	Cons	Water Depth
Floating to Fixed Wind Energy Concept (25 – 40m?)	• Tug deployable. • Could be used w/ suction buckets to minimize lake bed disturbances. • Could be maintained import.	• Not been demonstrated on large-scale commercial wind project. • Uncertain cost.	25m to 40m?
Dutch tri-floater (>50m) Tension leg platform (>50m) Ballast/mooring/buoyancy stabilized (>60m)	• Tug deployable. • Turbine sighting and interconnection flexibility. • Could be maintained import.	• Not been demonstrated on large-scale commercial wind project • Uncertain cost.	>50m
WindSea (35 – 200m) Blue H Prototype (tested 108 m) SWAY concept (>150m)	Deep water concepts requiring further demonstration.		Varies

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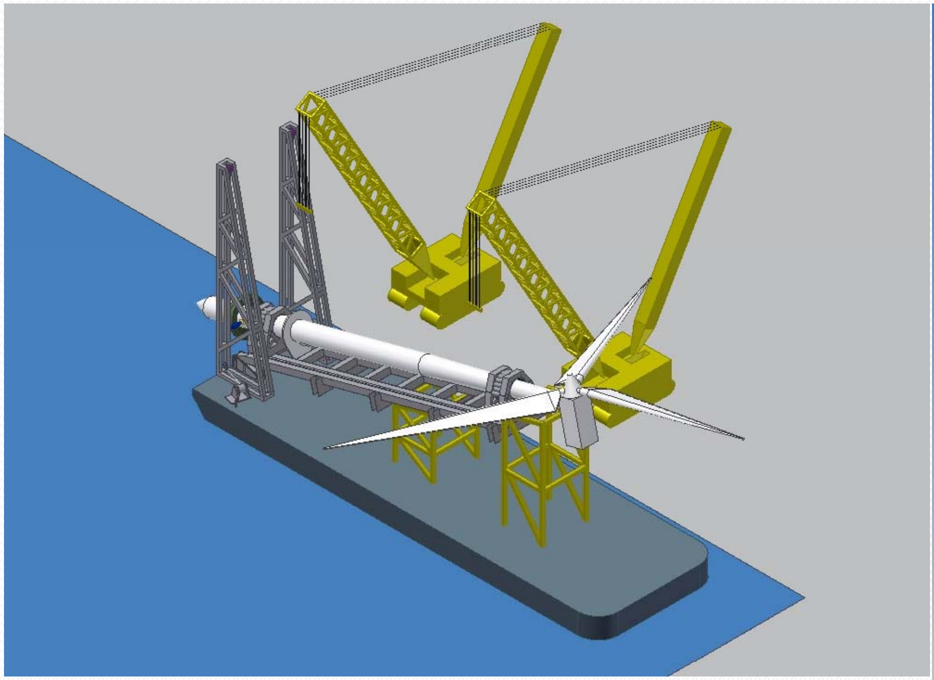
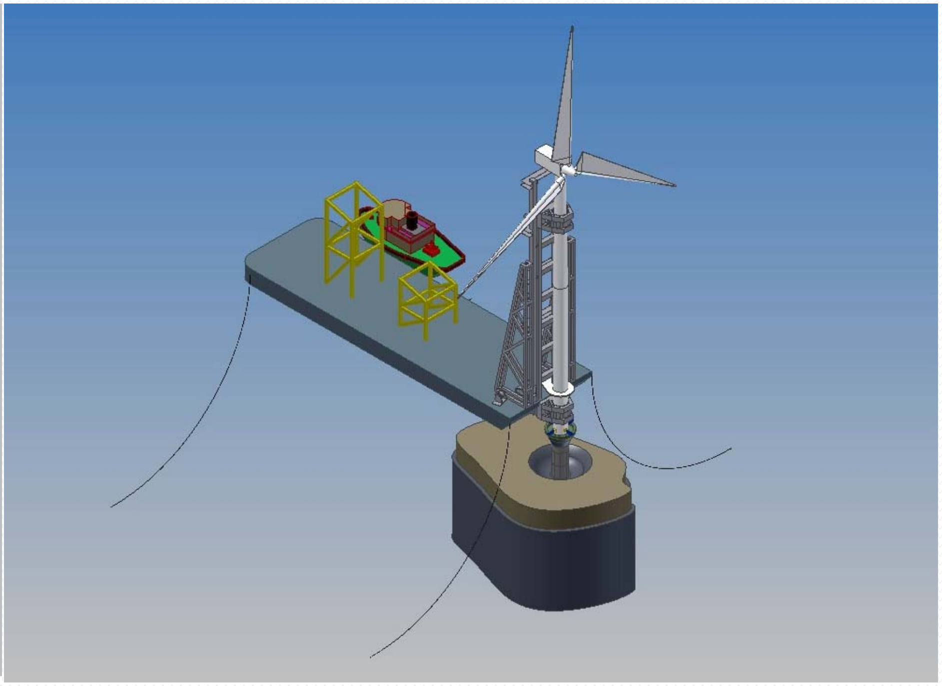
Merlin System





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Merlin system cont